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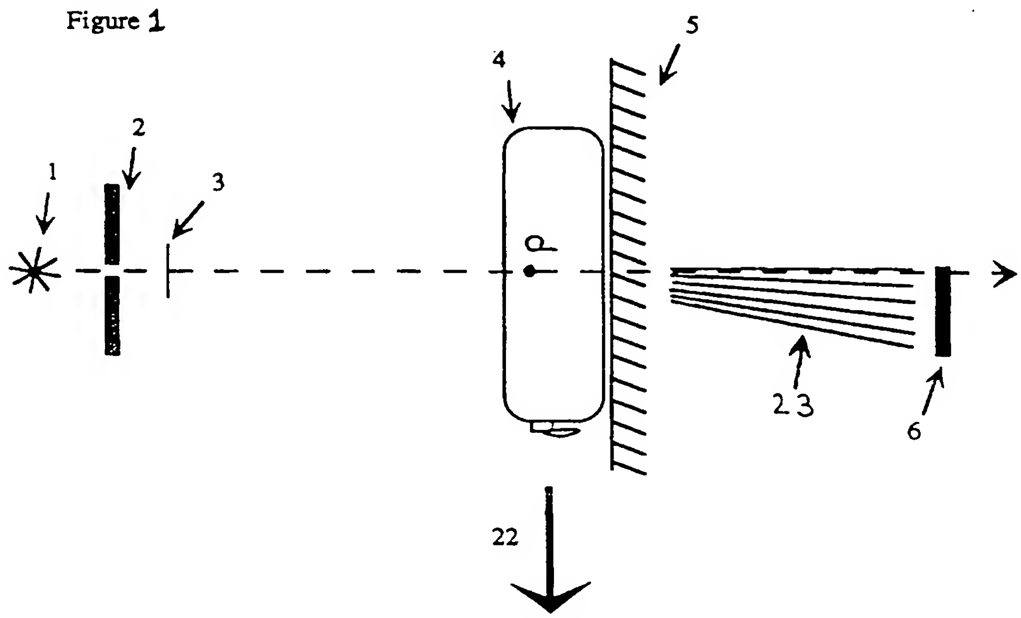
(54) **Three dimensional detection of contraband using x rays**

(57) In an x ray inspection system for detecting explosives and prohibited drugs an x ray source is arranged to irradiate a container 4 with a beam of x rays. Moveable attenuating sheets 23 collimate the x rays passing through the object 4 such that the detector 6 receives only those x rays coherently scattered through a predetermined angle from the volume element located at point P. Depth resolution is achieved by re-orientating the sheets 23 to aim the detector at a different volume element.

Figure 1



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1990.

GB 2 297 835 A

Figure 1

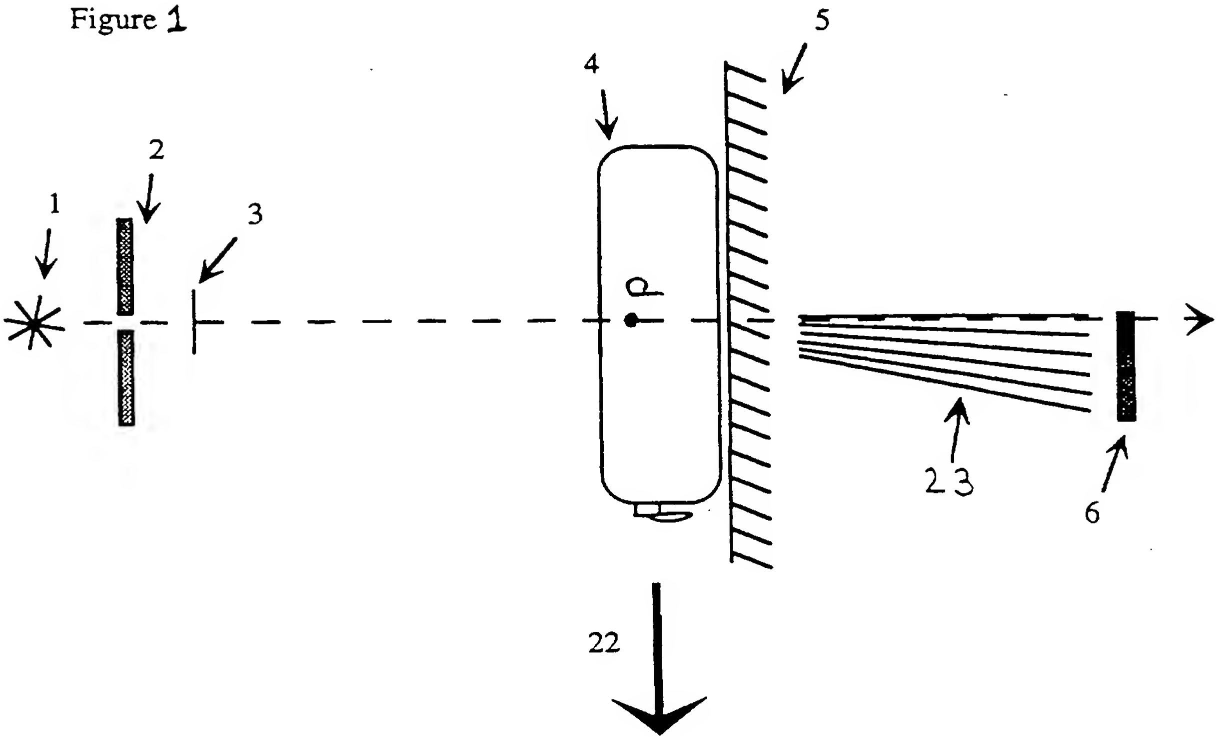


Figure 2

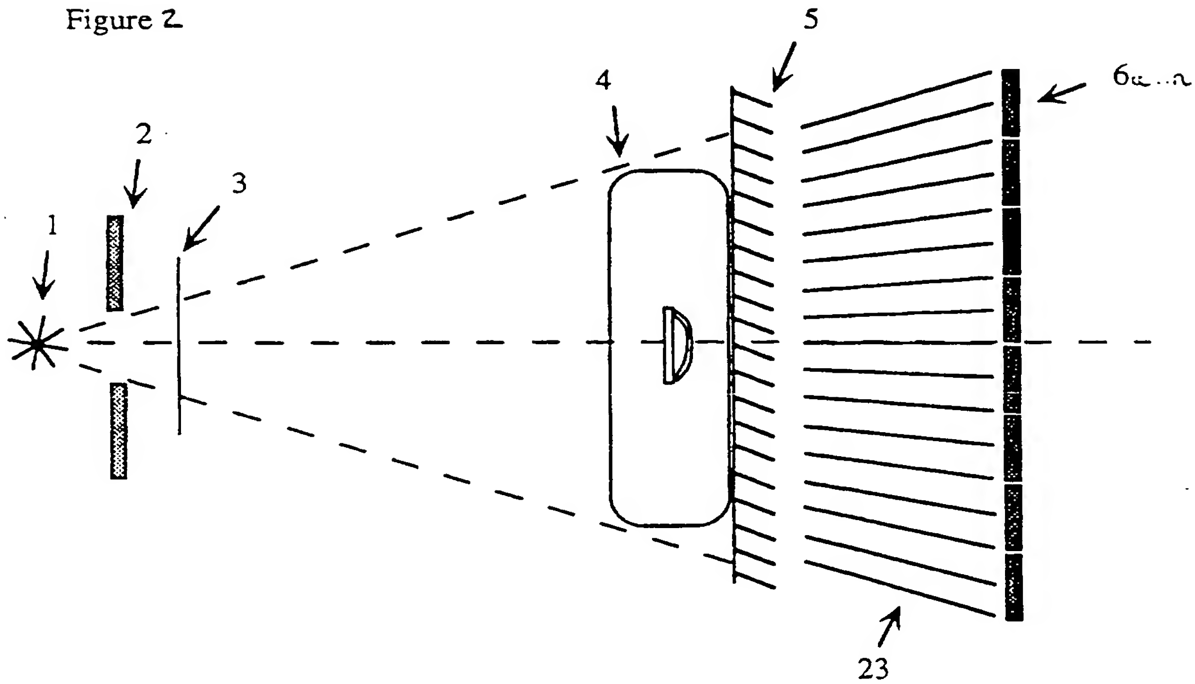


Figure 3

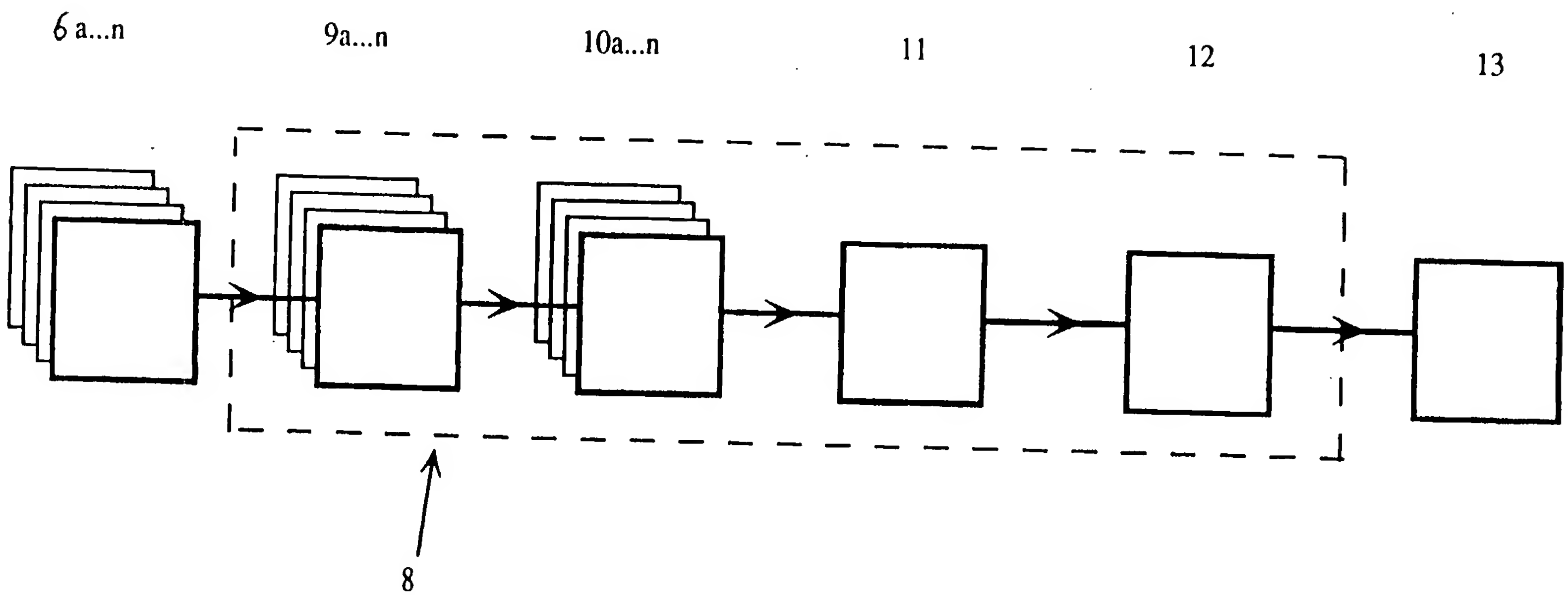


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Figure 4

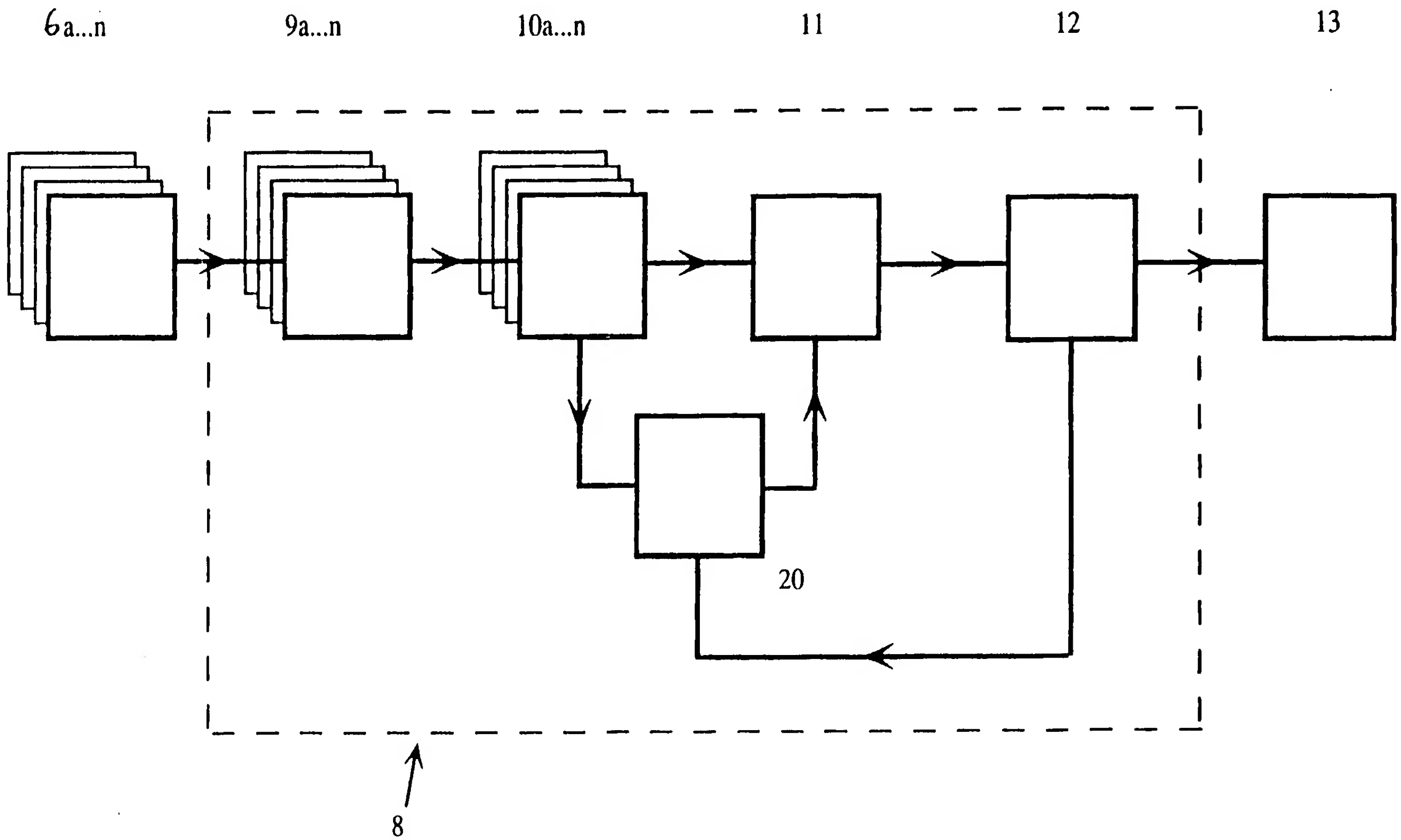


Figure 5A)

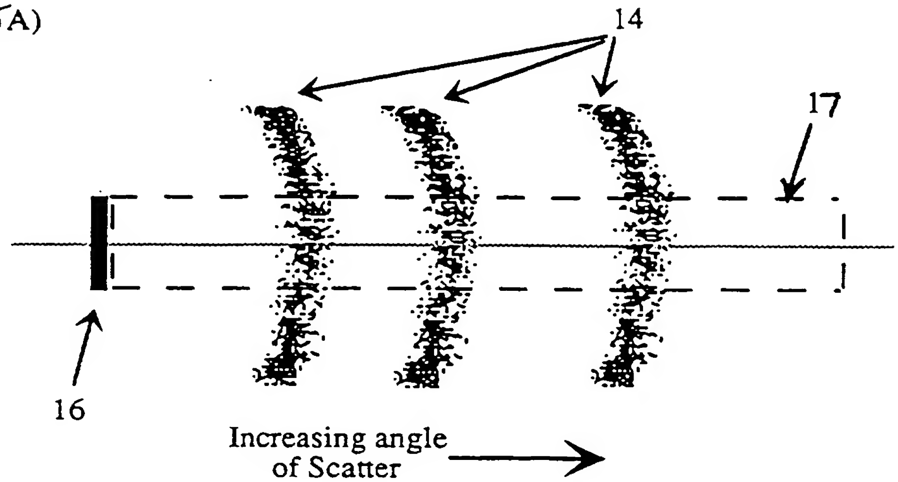
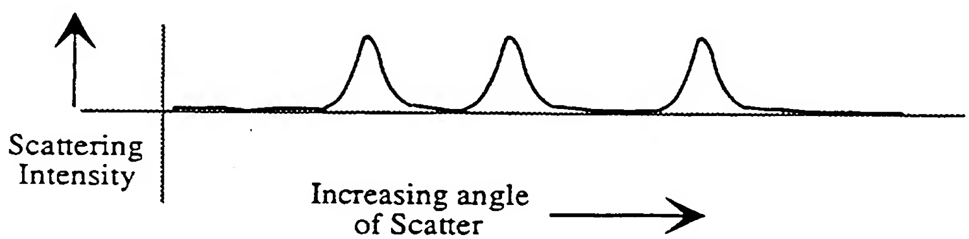


Figure 5B)



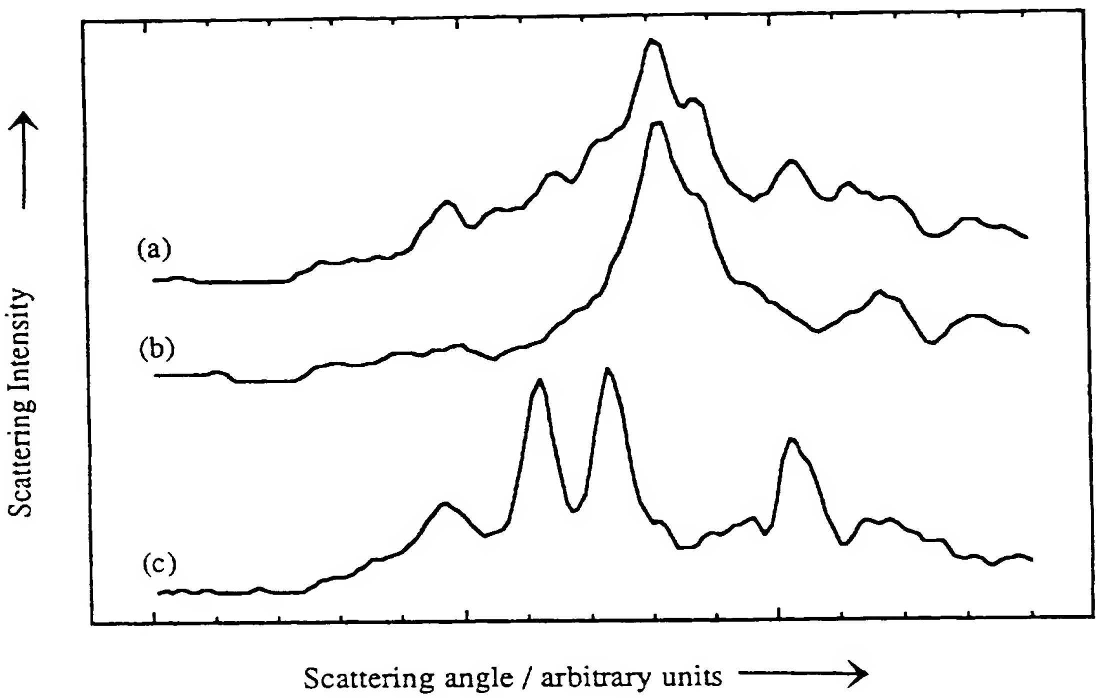

(a)
(b)
(c)
Scattering Intensity
Scattering angle / arbitrary units

Figure 6

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X-RAY INSPECTION SYSTEMS

This invention relates to the field of x-ray inspection systems and more particularly those inspection systems which use coherently scattered x-rays to detect the presence of explosive and incendiary materials, prohibited drugs or other illegally transported substances (hereinafter collectively referred to as "target material") in a container or the presence of imperfections or impurities in a material.

As the problems discussed in relation to known inspection systems below are equally valid for both container and material inspection systems they will be discussed only in relation to container inspection systems. The term "container" shall hereinafter be taken to refer to both the container and its contents.

Many systems which utilise x-rays have been developed for the inspection of containers such as baggage and parcels. These include dual energy transmission and backscatter imagers which essentially yield effective atomic number and density information in two or three dimensions. However, these systems are inherently chemically non-specific and rely on operator vigilance and interpretation during visual inspection of the outline of the contents of the containers inspected using these systems. A problem here is that many kinds of target material are not easily identifiable by their shape since they can be easily moulded or packed inside other items within the container to mask their presence. These materials are therefore not readily detectable using these systems.

One known system which overcomes this problem is described in the patent US 4 751 722. This discloses a system which analyses the intensities of x-rays from a monochromatic x-ray tube source which are coherently scattered through different small angles when passing through a container. This information is then used to generate an

angle dispersive x-ray spectrum which is characteristic of the ordered molecular structure of the material responsible for the scattering. The x-ray spectrum may then be passed to a data processing system where an automatic comparison is made with stored spectra characteristic of the target materials of interest in order to determine whether or not these target materials are present within the container.

However a problem with this system is that the contents of a container can only be resolved in the two dimensions of the voxel (volume element) in the plane perpendicular to the direction of travel of the unscattered x-rays, ignoring the third dimension in the direction of the unscattered beam, through the depth of the container. Where either the container or the target material has a third dimension greater than a few centimetres then depth resolution is required in order to satisfactorily identify the presence of a target material. This is because coherent scattering at different angles for different depths within a container from both target and other material cannot be differentiated from the scattering caused by target material at an angle of interest thereby causing the generated x-ray spectrum to become confused and identification of target material difficult.

A further a problem with this system is that the low x-ray flux generated by a monochromatic tube source results in too great an inspection time, making it impractical to use in situations where a large number or size of objects need to be rapidly inspected eg such as for containers in airports.

It is an aim of the present invention to provide an x-ray inspection system which alleviates at least some of the aforementioned problems.

It is well known that in crystalline materials incident x-rays can be coherently scattered from the crystal lattice. The angle, 2θ, measured relative to an axis through the source and material, at which

the x-rays are coherently scattered is dependent on the wavelength, λ, of the incident x-rays and on the crystal lattice spacing, d, and satisfies the equation:

$$\lambda = 2d \sin \theta \tag{1}$$

Thus by detecting the presence of incident x-rays of a known wavelength, λ, which have been coherently scattered through known angles, 2θ, satisfying equation (1) above, the crystalline target material responsible for the scattering can be identified.

According to the present invention there is provided an x-ray inspection system comprising an x-ray source disposed to irradiate an object to be inspected with a beam of x-rays projected from the source through the object, detection means capable of discriminating between the intensities of x-rays coherently scattered through the object at different angles to produce an output signal dependent on the intensity of the x-rays scattered through each of those angles, collimation means disposed between the detection means and the object and analysing means operably connected to the detection means to process the output signal to determine the presence of x-rays coherently scattered through one or more pre-determined angles wherein the collimation means is adapted to pass only x-rays coherently scattered at the different angles from a limited voxel depth.

The collimation means provides depth resolution in the direction of the x-ray beam which has the advantage that since only a limited depth of the object is inspected at any time then discrimination between scattering from target and that from other material is enhanced, as is discrimination between scattering at different angles from different depths of target material.

Usefully the collimation means and the object may be made moveable

relative to one another in the direction of the x-ray beam so as to vary the position of the voxel through the depth of the object. For ease of construction it is preferable if only the collimation means so moves.

Where the collimation means is moveable it is advantageous to provide a detection means capable of moving conjointly with the collimation means so as to maintain the relative separation between the two. This has the advantage that scattering through any given angle will be detected at substantially the same position on the detection means irrespective of the position of the voxel through the depth of the object.

The collimation means may comprise a plurality of sheets of x-ray attenuating material each extending along different radii of a circle having a centre coincident with the centre of the voxel from which scatter may be detected and spaced apart by a small angle of typically 0.5 degrees. If this small angular separation remains constant then the collimation means provides a small scattering voxel depth, in the direction of the unscattered x-ray beam, which depth is dependent on scattering angle. Advantageously, the collimation means may be moveable along the direction of the unscattered x-ray beam to vary the position of the centre of the voxel depth within the object so as to permit substantially the entire depth of the object to be inspected.

If it is desired to arrange for a constant voxel depth irrespective of the scattering angle, 2θ, then the radial separation, s, of the sheets should be calculated according to:

$$s = C \times \mathrm{Tan}(2\theta) \qquad (2)$$

where C is a constant dependent on both the required voxel depth and on instrumental dimensions.

In a preferred embodiment the x-ray source comprises a polychromatic x-ray generator and a cooperable balanced filter system. This has the advantage that the inspection time for a object may be reduced as compared with the inspection time required when the x-ray source consists of a monochromatic x-ray generator. The polychromatic generator provides a relatively high beam flux which allows for the rapid inspection of objects while the balanced filter system, used according to the method of Cooper et al (J. Phys E, 1985, Vol 18 pg 354) to provide an effective band-pass filter, permits the generation of an apparent angle dispersive x-ray spectrum substantially equivalent to one which would have been generated had a substantially monochromatic x-ray source been used. Furthermore, by arranging for each filter to be automatically placed in the beam path the need for operator intervention is removed.

A detector with moderate energy discrimination being sensitive to substantially only that x-ray energy within the band-pass region of the balanced filter system, for example one comprising an Anger camera, may be usefully employed in conjunction with the polychromatic x-ray generator to reduce a large proportion of Bremstrahlung radiation produced outside the energy region of interest. By so doing the signal to noise ratio of the generated spectrum is increased thereby allowing for a further reduction in inspection time.

Advantageously the detection means may be capable of simultaneously detecting x-rays scattered through a range of angles containing those predetermined angles of interest, for example by employing an imaging detector system or a number of discrete detector elements each arranged to detect at different discrete angles or narrow spread of angles, to produce an angle dispersive x-ray spectrum. This has an advantage that the inspection time for each object is reduced since data for the whole range of scattering angles of interest can be collected in parallel.

The x-ray inspection system preferably further comprises a collimator disposed between the source and object to produce a fan beam of x-rays in a plane perpendicular to that in which the angles, 2θ, are measured and the detection means is adapted to detect x-rays across the fan beam. This serves to further reduce the inspection time for each object.

Most advantageously the x-ray inspection system may additionally comprise an alarm means operably connected to the analyser means for producing an audio, visual or audio-visual alarm when the presence of x-rays scattered at one or more pre-determined angles has been determined. This provides a warning to an operator that a target material or the like has been detected within an object.

In order to increase the signal to noise ratio and hence the reliability of the system it is preferable that the analyser means is further adapted to process a signal formed from a number of voxels to be representative of the total signal from a localised region of the object under inspection to determine the presence within that region of x-rays scattered at one or more pre-determined angles.

Most usefully there is also provided a means, such as a conveyor belt, for transporting the object to be inspected through the fan beam.

Embodiments of the x-ray inspection system according to the present invention, when employed to inspect containers, will now be described with reference to the accompanying drawings in which:

Figure 1 is a side view of an x-ray inspection system;

Figure 2 is a front view of the same system;

Figure 3 is a schematic representation of a first embodiment of the analyser means;

Figure 4 is a schematic representation of a second embodiment of the analyser means;

Figure 5 shows (A) a typical scattering image and (B) a reduced information scattering profile produced from this image; and

Figure 6 shows representitive scattering profiles obtained using different explosives.

Referring now to Figures 1 and 2, x-rays from the polychromatic x-ray source 1 are collimated into a narrow fan beam by the slit collimator 2. This fan beam passes through a filter in the balanced filter system 3 before being incident upon a container 4 which is on a conveyor belt 5 moving at a constant velocity in the direction of 22. The balanced filter system 3 has two filters which when used sequentially act as a single, narrow, band-pass filter. The first filter constructed from thulium and the second filter from erbium which together have K absorption edges which bracket the tungsten $K\alpha$ 1 and $K\alpha$ 2 fluorescence lines of a tungsten anode x-ray source.

X-rays passing through this container 4 which are elastically scattered through a range of angles 2θ by target material within the container 4 are are collimated by an array of metal foil sheets 23, arranged along radii of a circle centred at point P within the container 4 such that scatter from only a limited voxel depth (typically 1 cm) centred at P, for the range of angles of interest (typically 10°), is capable of being detected.

Indeed, the radial separation of each sheet may be calculated using equation (2) for which a value of C=3.19 is obtained for a constant voxel depth of 3.2cm; a distance between the point P and the nearest edges of the sheets of 25cm; and a sheet length of 25cm.

During the acquisition of the scattered beam from a particular voxel all of the sheets 23 are rotated out of the plane of the fan beam about P by a small angle which is typically the average spacing of the sheets 23. This displaces, over time, the radial position of the sheets and avoids loss of information due to total attenuation of the scattered x-rays at the discrete scattering angles in which the sheets are orientated. The sheets may be returned to their original positions and the same displacement repeated for each voxel which is inspected or the sheets may be displaced alternately by the same amount in opposite directions for alternate voxels.

In order to inspect the full depth of the container 4 the sheets 23 are moveable together along the direction of the unscattered x-ray beam (as represented by the broken line in Figure 1) so as to move the inspection centre P by the same amount as the sheets 23 are moved.

The collimated x-rays are detected simultaneously over all of the range of angles, 2Θ, by one of an array of detectors 6a..n which are disposed across the width of the fan beam. Each of the detectors 6a..n comprises a large format photon counting camera, for example an x-ray image intensifier tube and low noise camera combination or a scintillator and intensified CCD camera, having a spatial resolution of the order of hundreds of microns and a sensitive area of several square centimetres or more over which incident x-rays can be detected. The individual detectors 6a..n are arranged to produce an output representative of the intensities and positions of scattered x-rays incident upon the detector.

Referring now to Figure 3, the output signal from each of the detectors 6a..n is then passed to the analysing means 8, depicted by the broken lines, which comprises an array of differential image calculators 9a..n, one for each detector 6a..n; an array of scattering profile generators 10a..n, one for each calculator 9a..n; a spectrum characteristics generator 11 and a spectrum characteristics

comparator 12.

The output signal from each detector 6a..n is acquired into an associated differential image calculator 9a..n to produce a scattering image. Each image is then processed by an associated scattering profile generator 10a..n to reduce the amount of data which is passed to the spectrum characteristics generator 11 by discarding information in those parts of the image associated with areas of the detector corresponding to scattering locations through which x-rays are not expected, by equation (1), to be coherently scattered by a target material of interest. The information in those remaining areas representative of a particular scattering angle is then averaged to further reduce the data to be passed to the spectrum characteristics generator 11. This reduced information scattering profile is then passed to the spectrum characteristics generator 11 where the angular positions and intensities of relevant scattering features within the profile are determined. The characteristics measured in each profile are then passed to the spectrum characteristics comparator 12 where a determination is made as to the presence within the container 4 of any target material by comparing these characteristics with those stored in the comparator 12. If it is determined that target material is present an activating signal is sent from the comparator 12 to the alarm 13 which serves to alert the operator to its presence.

In a second embodiment of the invention shown in Figure 4 the analysing means 8 is similar to that described above except that a profile adder 20 is incorporated between the profile generators 10a..n and the spectrum characteristics generator 11. When the presence of target material has been determined from a single profile, as described above, a first activating signal from the comparator 12 is relayed to the adder 20 which then operates to sum the profiles from a small number of profile generators 10a..n to produce a single profile which is representative of x-rays elastically scattered from a localised region of the container. This single profile is then passed

to the spectrum characteristics generator 11 and processed as previously described. In the event that the comparator 12 determines the presence of target material from this summed profile a second activating signal from the comparator 12 is relayed to the alarm 13. This affords some protection against an incorrect determination of the presence of target material because the signal to noise ratio is greater for this profile than for the individual component profiles.

It will be readily apparent to those skilled in the art that the functions of all of the above described components of the analysing means can be performed by one suitably programmed computer.

The scattering image produced by the differential image calculators 9a..n is illustrated in Figure 5A where the scattering bands 14 correspond to part of the concentric rings of x-ray photons coherently scattered by the target voxel. The region of a detector 6a..n irradiated by unscattered x-rays is represented by 16 and the area used to generate the reduced information scattering profile of Figure 5B is represented by the broken lines 17. As can be seen from Figure 5B peaks in intensity of scattered x-rays correspond to the scattering bands 14.

Figure 6 shows the scattering profiles obtained from 13 mm thick samples of (a) Semtex-H; (b) wet pure PETN and (c) wet pure RDX using the embodiment of Figures 1 and 2 and sampling for 100 seconds.

CLAIMS

1. An x-ray inspection system comprising an x-ray source disposed to irradiate an object to be inspected with a beam of x-rays projected from the source through the object, detection means capable of discriminating between the intensities of x-rays coherently scattered through the object at different angles to produce an output signal dependent on the intensity of the x-rays scattered through each of those angles, collimation means disposed between the detection means and the object and analysing means operably connected to the detection means to process the output signal to determine the presence of x-rays coherently scattered through one or more pre-determined angles wherein the collimation means is adapted to pass only x-rays coherently scattered at the different angles from a limited voxel depth.

2. An x-ray inspection system as claimed in Claim 1 wherein the collimation means comprises a plurality of sheets of x-ray attenuating material each extending along different radii of a circle having a centre coincident with the centre of the voxel from which scatter may be detected and spaced apart by a small angle.

3. An x-ray inspection system as claimed in Claim 2 wherein each of the plurality of sheets are spaced apart by varying amounts so as to define a voxel depth which is constant for the different angles through which x-rays may be coherently scattered.

4. An x-ray inspection system as claimed in any preceding claim wherein the collimation means is moveable relative to the object to be inspected in the direction of the unscattered x-ray beam so as to vary the position of the voxel through the depth of the object.

5. An x-ray system as claimed in Claim 4 wherein the detection means is adapted to move conjointly with the collimation means.

6. An x-ray inspection system as claimed in any preceding claim wherein the x-ray source comprises a polychromatic x-ray generator and a cooperable balanced filter system.

7. An x-ray inspection system as claimed in Claim 6 wherein the detection means comprises a detector adapted to be sensitive to substantially only that x-ray energy within the band-pass region of the balanced filter system.

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Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report)	Application number GB 9502460.0
Relevant Technical Fields (i) UK Cl (Ed.N) G1A (ACA, AMAC, AMHR, AMV, AMZ, ADB, ACK, ATJ); H5R (REG, REY, RAT) (ii) Int Cl (Ed.6) G01N 23/20, 23/201, 23/207, 23/205, 33/22, 23/02, B07C 5/34	Search Examiner MATTHEW GILLARD Date of completion of Search 3 APRIL 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- ALL

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X	GB 1463054	(EMI) whole document	1, 2, 4, 5
X	EP 0354045 A2	(ION TRACK) column 3, lines 25 to 37	1
X	US 5265144	(PHILIPS) whole document	1-3
X	US 4956856	(PHILIPS) column 7, lines 11 to 24	1

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